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TITLE: **The Los Alamos SuperScrub™: Supercritical Carbon Dioxide System Utilities and Consumables Study**

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THE LOS ALAMOS SUPERSCRUB™: SUPERCRITICAL CARBON DIOXIDE SYSTEM UTILITIES AND CONSUMABLES STUDY

by

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ABSTRACT

A study was undertaken to determine the electrical and other utilities usage of the SuperScrub™ system. The purpose of the experiments being conducted at Los Alamos is to prove or disprove the feasibility of precision cleaning for solvent and waste reduction using supercritical carbon dioxide. An actual dollars value-versus-time has been calculated for predetermined pressures, flows, and temperatures. State-of-the-art menu- and software-driven instrumentation were utilized to generate exacting results. It is hoped that these results will prove of immediate benefit to those industries interested in but concerned about the cost of changing over to carbon dioxide cleaning on both small- and large-scale operations.

INTRODUCTION

The Los Alamos SuperScrub™ is a large supercritical carbon dioxide system. It is mechanically and technically highly sophisticated with variable temperature, pressure and flow. Pressures as high as 5000 psi, temperatures from room to as high as 60°C, and flow rates as high as 500 lbs/hr are attainable utilizing forty-five separate variable numerical input commands and thirteen positive/negative machine event manual commands. Computer control is accomplished using Genesis™ software by Iconics, a Hewlett Packard (H.P.) PC, and a General Electric Fanuc model 90-30 programmable controller system.

The SuperScrub™ was developed by Autoclave Engineers of Erie, PA. At the time of this writing only two systems of this type are in use, outside of Autoclave Engineers, in the United States. The Los Alamos machine is unit number two and is an updated design of the prototype.

The four major integral components of this system are the computer control, the pumping and flow system, a 60-1iter, high-pressure extraction vessel, and a contaminants separation vessel.

Figure 1 is a system overview showing the basic layout of the operation. The extraction vessel, also known as the cleaning vessel, is physically separated from the main pumping and flow operation. For clarity, it is shown closely positioned on the schematic.

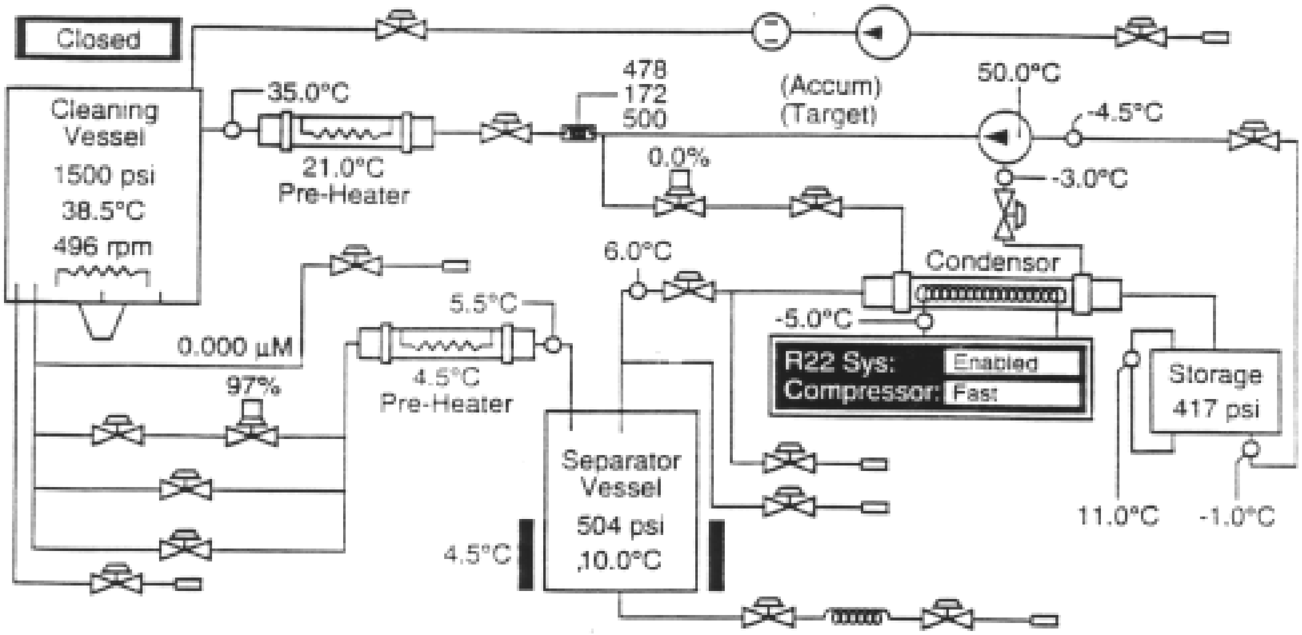

Figure 1. System overview of the Los Alamos SuperScrub™ supercritical carbon dioxide system.

System flow starts from the 100-liter liquid storage tank on the bottom right and proceeds up and left to the CVI-manufactured cryo-pump, continuing to the left to the cleaning vessel preheater and then to the pressurized 60 liter cleaning vessel. This vessel also contains a heater used to maintain the supercritical carbon dioxide at a predetermined temperature. Pressure control is accomplished by number of air-operated valves both before and after the cleaning vessel. The flow then continues to a separator vessel pre-heater and on to the separator vessel itself. At this point the contaminants are removed, and the carbon dioxide travels to a condenser where it is cooled to a liquid and resumed to the storage tank.

METHODOLOGY

A long series of machine runs were organized in such a manner that the previous run did not cause an error by way of residual thermal effect. That is, the large masses within the machine were allowed to equilibrate back to room temperature before the next run was made. Also, runs were made from lower to higher temperatures and pressures.

Each data run consisted of a total time of sixty minutes. This time was an absolute measure starting with the autocycle start and ending with the cleaning vessel at 0 psi. The measured time error was approximately plus or minus 5% over the series of data runs.

Monitored runs were made at 1500 psi, 2500 psi, and 3500 psi, and at temperatures of 30°, 40°, and 50°C. All electrical measurements were made utilizing a Basic Measuring Instruments (B.M.I.) model 3030A Powerprofiler™. Costs were calculated at a 10¢/kilowatt hour rate but can be readily recalculated for a different structure.

The B.M.I. instrument uses inductive pickups and direct power line hookups to develop charts as seen in Figures 2 through 5, as well as performing phase characterization, which includes orientation and balance. The B.M.I. is both menu- and software-driven allowing for rapid calculation of a predetermined rate structure as well as producing a number of highly resolvable charts.

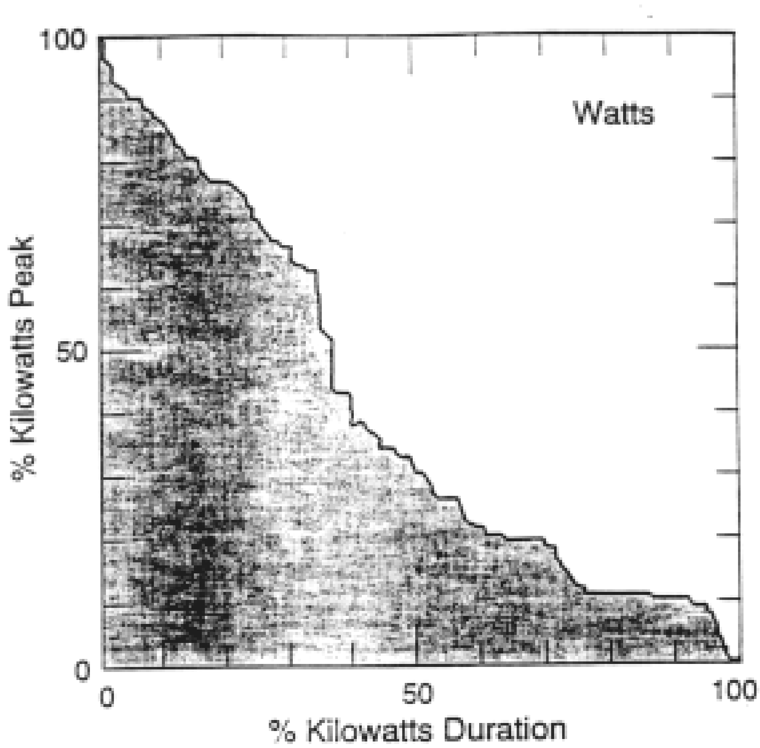

Figure 2. Load curve: per cent wattage peak vs. duration.
TA-35, Bldg. 125, Rm A101, Dec. 16, 1993

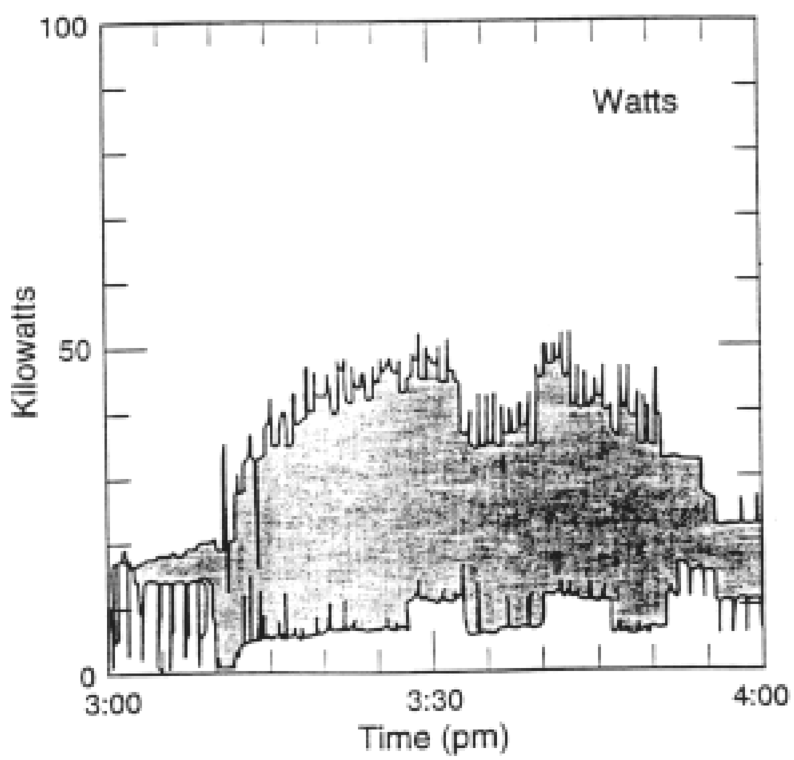

Figure 3. Instantaneous power: 5 min/div. horiz.,
TA-35, Bldg. 125, Rm A101, Dec. 16, 1993

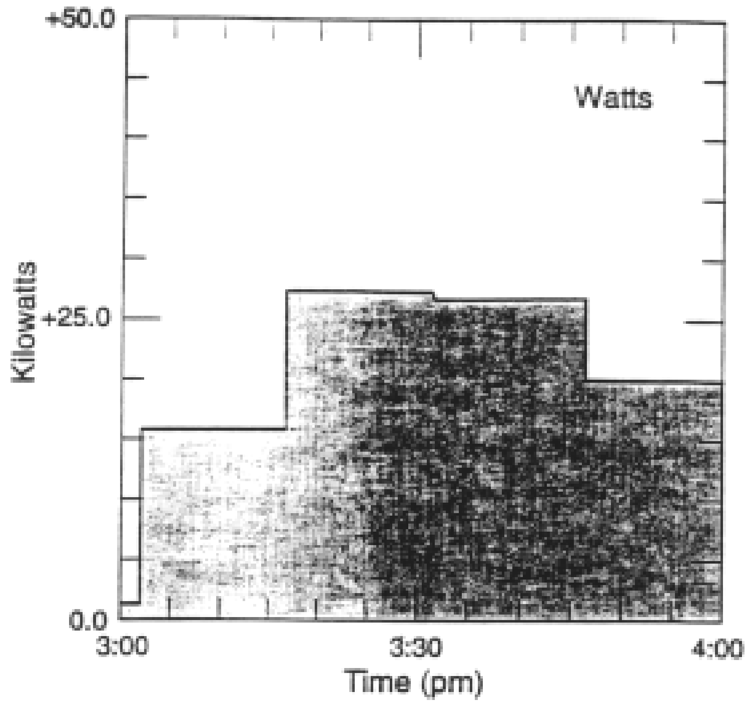

Figure 4. Billing demand: 5 min/div. horiz., TA-35, Bldg. 125, Rm. A101, Dec. 16, 1993

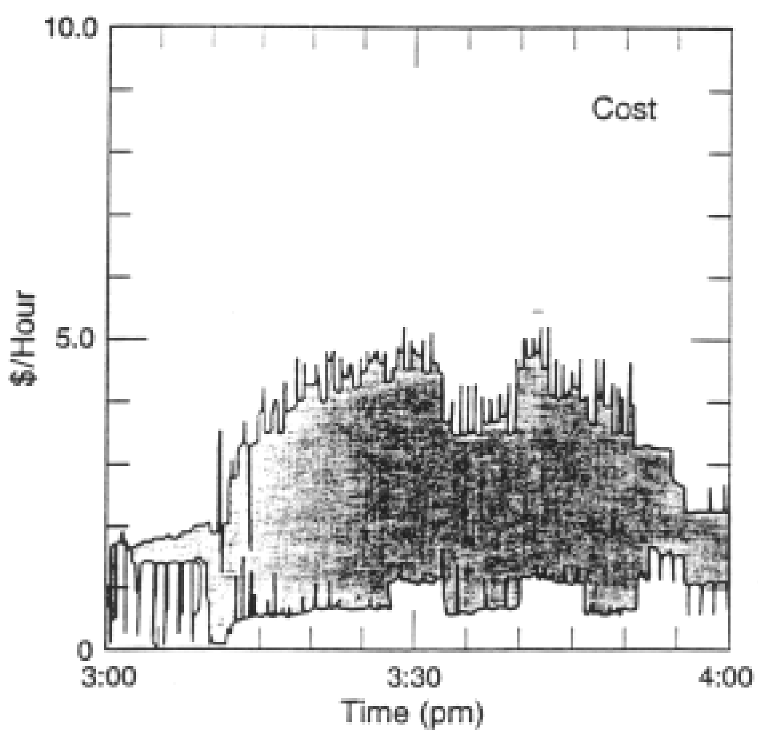

Figure 5. Cash flow, 5 min/div. horiz., TA-35, Bldg. 125, Rm. A101, Dec. 16, 1993

The SuperScrub™ is served by a dedicated 480-volt ac, 4-wire delta phase 130 amp. circuit. The inductive pickups were installed directly at this switch station. Most all the machine's electrical usage is through this circuit. This includes, in addition to the high electrical usage components, such items as internal machine lighting, a small strip heater, fans, co-solvent pump, and various control devices, all small consumers of electricity. The two exceptions to this are the computers, an H.P. Vectra for machine control, and an IBM for data collection and research purposes, and the remotely located freon-to-air heat exchanger/condenser, which will be addressed in some detail later.

MAJOR POINT SOURCE CONSUMERS

There are six components within the machine that as a group consume a major portion of all electrical power used

- a CVI positive displacement cryo/pump powered by a 10 hp, 480-volt ac, three-phase motor with a peak current usage of 13.3 amps. or 6.4 kilowatts.
- Located at four places in the carbon dioxide flow stream, 12-kilowatt/480-volt ac, three-phase screw plug emmersion heaters, which collectively could potentially use up to 100 amps.
- an R22, 17-ton, refrigeration unit used by the Super Scrub™ as a heat exchanger for the gaseous carbon dioxide, returning it to the liquid state and back into the main storage tank. The refrigeration compressor is of a two-speed design capable of consuming as much as 21.2 kilowatts on high speed and 6.4 kilowatts on low speed.

THE AIR-COOLED FREON HEAT EXCHANGER

The Super Scrub™ requires cooling for the R22 refrigeration system. The original method of cooling the freon was with the facility's industrial chilled water. As a result of long-term problems with this system, it became necessary to supply another cooling method. A model 349 Libert three-fan, air-cooled heat exchanger was installed. The engineering and retrofit were accomplished by the Los Alamos facility. This equipment is not supplied or offered as a substitute with the SuperScrub™.

The new exchanger is located approximately 40 feet remote, outside, on top of the facility's roof. It has a dissipation capacity of approximately 315,000 BTUs after derating for Los Alamos' 7000-foot elevation. The exchanger is served by a dedicated 25-amp, 230-volt, 3-phase circuit.

Electrical usage measurements on the heat exchanger were made as inductive pickup voltage measurements using Bell Inc. model CG-100A Guns™. Three individual pickups were attached simultaneously to each of the incoming phases. Readouts were taken first on a Tektronics 7904 oscilloscope using 7A26 plug-ins, and then on a Fluke model 8020B multimeter. In addition, visual observations were made of the fan's operation. The machine's operating conditions during data taking were pressure at 2000 psi, flow at 500 lbs/hr and cleaning vessel temperature at 40°C. The outside weather conditions were clear and sunny. The temperature was 41°F, and a light 3 mph wind was blowing. The relative humidity was 14%.

Data were recorded over a 60-minute period. During this time it was noted that one fan turned very slowly, possibly the result of heat convection. The measured electrical energy usage was less than 1 amp peak.

When comparing these results with the cost of operating an industrial chilled water system required to supply 30 gal/min at 45°F, the benefits of air cooling become quite obvious. Routine maintenance and electrical usage for pumping would make water cooling considerably more costly when compared to air cooling.

MEASUREMENT CONSIDERATIONS

It must be explained at this point that all six of the major electrical consumers in the machine could be described as pulsed power users. The emmersion heaters rarely, except at the highest operating temperatures of 50° to 60°C, supply a full 12-kilowatt heating, and then they are cycled off and on only as needed. Inductive pickups were installed on the incoming power to the l0-hp cryopump motor, and, as expected, current usage varied by a factor of about 80% between the power stroke and the piston return, thereby giving a peak average usage considerably lower than motor-plate specification.

Also, during this test series the pumping rate of 500 lbs/hr was never changed. Lower pumping rates would, of course, be less energy intense.

The 17-ton R22 refrigeration system used to cool the carbon dioxide gas back to liquid is in operation continuously during flow. It does, however, switch from low- to high-speed, changing its consumption from about 6 kilowatts to about 22 kilowatts.

THE COST OF IDLE TIME

When the machine is idle, the pressure slowly builds up in the liquid storage vessel and the heat exchanger/condenser. Routinely, the refrigeration compressor cycles on slow speed when vessel pressure reaches a preset level of 400 psi, thereby reducing the storage vessel pressure to 340 psi. This function is seen to occur on an average of only once per hour normally and is very inexpensive. Figures 6 and 7, instantaneous power and cash flow, are the result of one hour of idle time and show that the compressor came on only once during this hour using power at a rate of 5 kilowatts for a very short time and costing less than five cents. Also observable on these graphs is a level above zero cost per hour. This is the standard continuous use of power by controls, strip heater on the refrigeration compressor, and such, and is very low-cost.

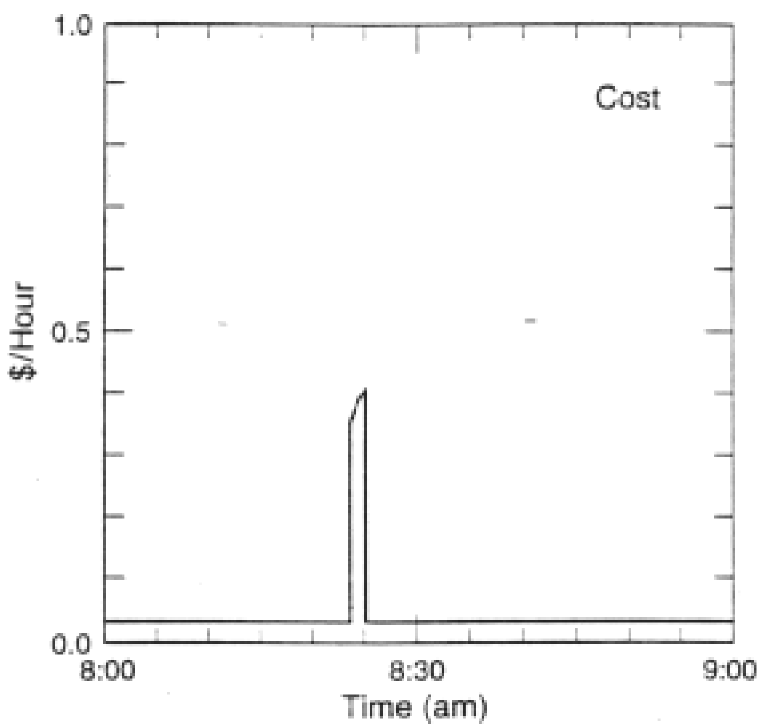

Figure 6. Cash flow: Powerprofiler Site, 5 min/div. horiz., Jan. 27, 1994.

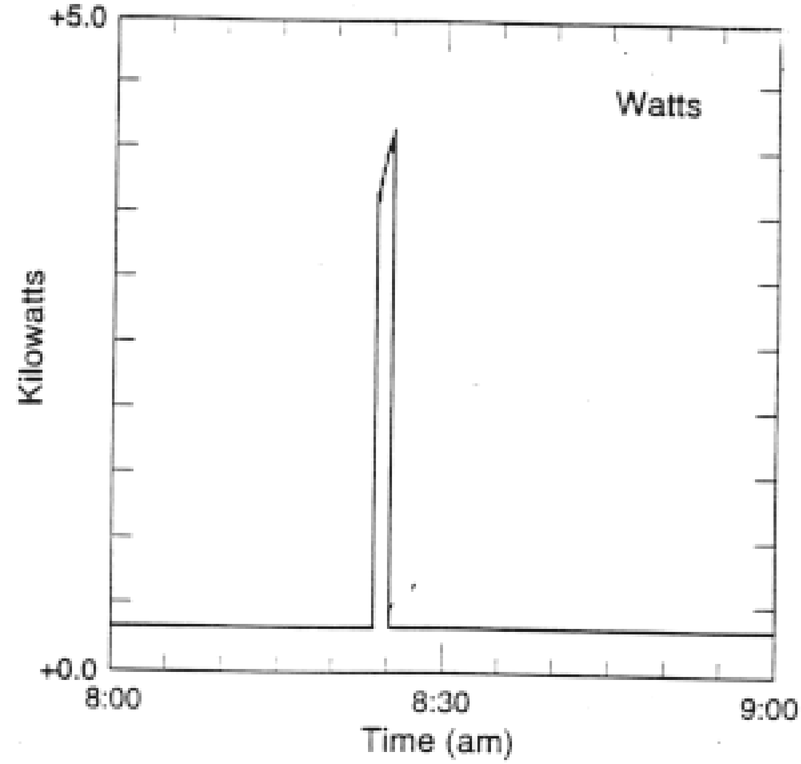

Figure 7. Instantaneous power: Powerprofiler Site, 5 min/div. horiz., Jan. 27, 1994

INITIAL CARBON DIOXIDE FILLING OF THE SUPER SCRUB™

Figure 8 shows the cumulative instantaneous power usage necessary to fill the machine from scratch. The recorded time to fill was 82 minutes.

The carbon dioxide source was a gas-bottle rack containing seven 50-lb cylinders on a common manifold of one-half-inch stainless tubing with a run of about 40 feet to the machine. The cylinders were at room temperature and at a pressure of approximately 900 lbs.

At no time during the fill did the refrigeration compressor run at high speed, and at no time, as can be seen in Figure 8, did the instantaneous power usage exceed 6 kilowatts. The total electrical cost to fill the machine was 15¢ at a total kilowatt usage of roughly 1.6 as calculated at the 10¢ per kilowatt hour rate.

A total fill from scratch is not normally required during routine daily operations; however, if the carbon dioxide should somehow become contaminated or if power to the machine is interrupted for a period in excess of two hours, then venting to the atmosphere would become necessary.

One hundred liters is the total volumetric size of the carbon dioxide liquid storage vessel. However, only about 80% or 80 liters of carbon dioxide is required to activate the automatic fill shutoff. A calculation based on a cost per pound of liquid at 10¢ per pound means that a total fill cost for the carbon dioxide would be about $17 plus electrical costs.

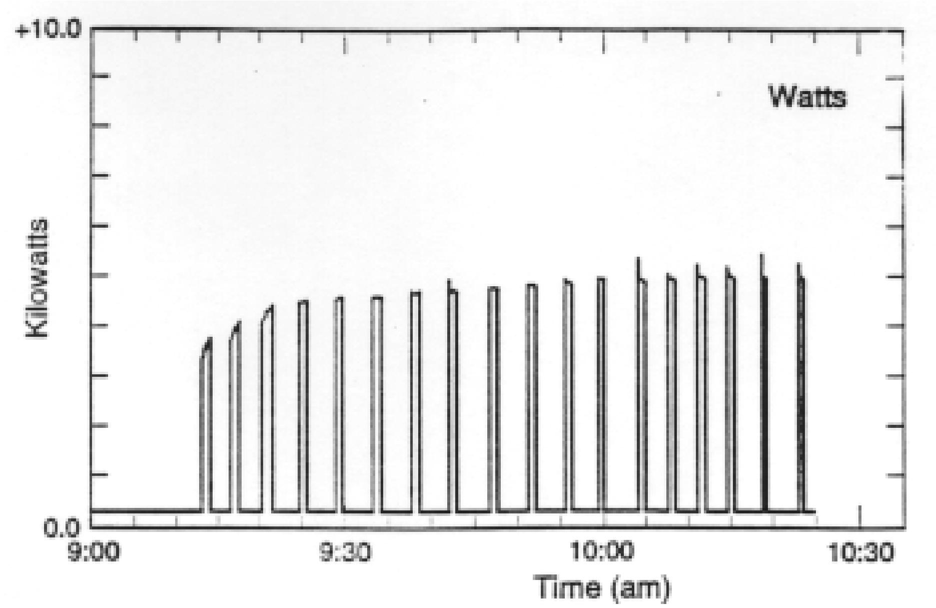

Figure 8. Instantaneous power: Powerprofiler Site, 5 min/div. horiz., Feb. 2, 1994

COMPRESSED AIR USAGE

The Super Scrub™ machine uses compressed air to operate numerous control valves throughout the flow stream. A total of 10 SCPM at 90-100 psi is sufficient for this purpose. A unit such as a standard Sears 2-hp, 20 gal. home workshop air compressor would be large enough to perform this function. These typically use 120-volt ac with a peak current usage of 15 amps or less than 2 kilowatts at 10¢ per kilowatt hour, less than 20¢ per hour.

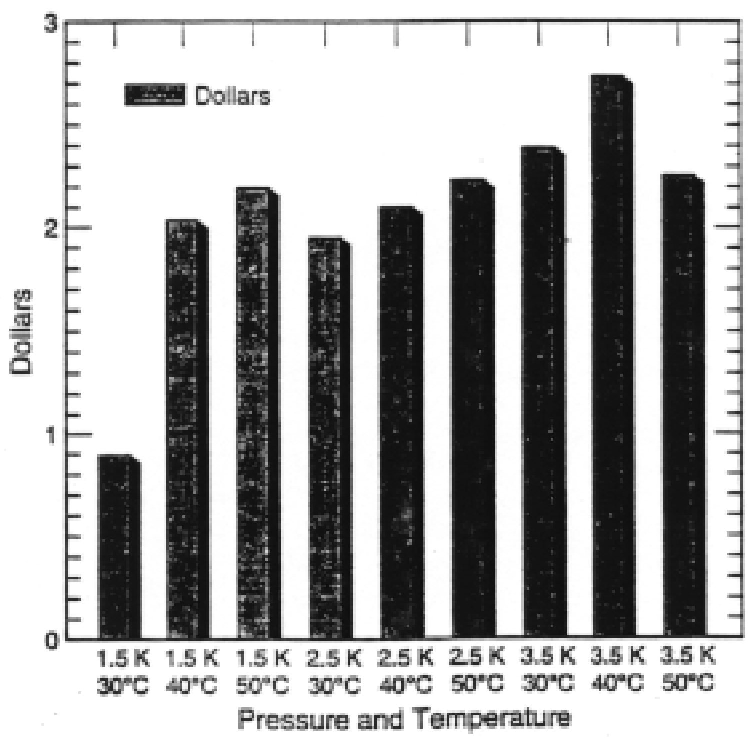

Figure 9. Electrical usage for one hour in dollars.

CONCLUSION

The Los Alamos Super Scrub™ machine is quite inexpensive to operate from an electrical as well as a consumables standpoint. Figure 9 shows a dollar-per-kilowatt-hour number for measured electrical power usage at the main machine buss. As can be seen, the higher operating temperatures are more likely than higher pressures to cause higher operating costs.

When adding up all the costs of operation previously described, it is easily seen that the electrical costs would be small when compared to operating labor, routine maintenance, and repair.

ACKNOWLEDGMENTS

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